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Toyota's Powertrain Philosophy for customer's smile

Toyota's Antriebsstrangphilosophie für höchste Kundenzufriedenheit

Abstract

In-house development of core technologies is the key element of Toyota Motor Corporation's philosophy to deliver optimum powertrains to customers in every region around the world.

Historically, Toyota has developed its engines, transmissions, and electronic components in-house. More recently, Toyota has extended this approach to motors, inverters, and batteries for hybrid electric vehicles (HEVs). Furthermore, last year, Toyota also began production of its in-house developed fuel cell (FC) powertrain components.

Each country and region around the world has a different energy situation, road environment, and customer expectations. Rolling out a single powertrain in every region at the same time is unlikely to provide an effective solution for energy and environmental issues. For example, differences in the road environment, such as the state of highways and congestion, yearly distances driven, fuel quality and price, and the availability of alternative fuels, are important consideration points of the optimum powertrain that we wish to deliver.

Toyota's approach is to adopt the most efficient powertrains for a particular region using the technological know-how built-up through its history of in-house development of a full-range of powertrains.

In addition to the development of a future vehicle-mobilized society using energy-saving technology and the adoption of sustainable energy, Toyota is also taking the lead in the creation and proposal of ways to use energy across the whole of society.

Toyota believes these activities lead to the true “Customer's smile”.

Kurzfassung

Die Entwicklung von Kerntechnologien im eigenen Hause ist Teil der Grundphilosophie von Toyota Motor Corporation, um Kunden in aller Welt optimale Antriebsstränge anbieten zu können.

In der Regel entwickelt Toyota die Motoren, Getriebe und elektronischen Bauteile selbst. Seit einiger Zeit werden nun auch Elektromotoren, Wechselrichter und Batterien für Hybrid-Elektrofahrzeuge (HEV) im eigenen Hause entwickelt. Im letzten Jahr hat Toyota die Serienproduktion der selbst entwickelten Brennstoffzelle (FC) begonnen.

In den Ländern und Regionen der Welt gelten jeweils unterschiedliche Bedingungen bezüglich der Energiesituation, Straßenverhältnisse und Erwartungen der Kunden. Daher ist der Einsatz einer einzigen Antriebsstrangtechnologie in allen

Regionen keine zielführende Lösung für die Energie- und Umweltfragen. Unterschiedliche Verkehrsbedingungen wie z.B. Autobahngeschwindigkeiten und Verkehrsstauungen, die jährlichen Fahrleistungen, Qualität und Preisniveau des Kraftstoffs und die Verfügbarkeit alternativer Kraftstoffe sind Faktoren, die für die Entwicklung eines aus unserer Sicht optimalen Antriebsstrangs für eine Region einzubeziehen sind.

Toyotas Ansatz ist, mit dem aus der eigenständigen Entwicklung und Herstellung der Antriebsstränge gewonnenen Knowhow für jede Region den jeweils effektivsten Antriebsstrang bereitzustellen.

Toyota wird im Hinblick auf zukünftige Technologien zur Energieeinsparung und Nutzung nachhaltiger Energiequellen nicht nur im Fahrzeugbereich, sondern auch bei Konzepten und Entwürfen für die Energienutzung im gesamten Gesellschaftsbereich eine führende Rolle spielen.

Toyota ist der Überzeugung, dass diese Vorgangsweise ein wesentlicher Beitrag zu höchster Kundenzufriedenheit ist.

1. Introduction

The demand for oil is expected to continue rising in the future as the emerging markets experience rapid motorization. As a result, the reduction of oil consumption and adoption of alternate fuels are of critical importance from the standpoint of the energy security of each country. Automakers will continue to play an increasingly vital role in the reduction of CO_2 emissions to help restrict climatic fluctuations such as global warming, as well as in the prevention of pollution.

In addition to addressing these issues, automakers are also expected to deliver vehicles that are convenient to use and fun-to-drive. In the powertrain field, this means developing and adopting powertrains that maximize an exciting driving feeling and the power delivered by the vehicle, while reducing tank-to-wheel energy consumption and minimizing the burden on the environment (Fig. 1).

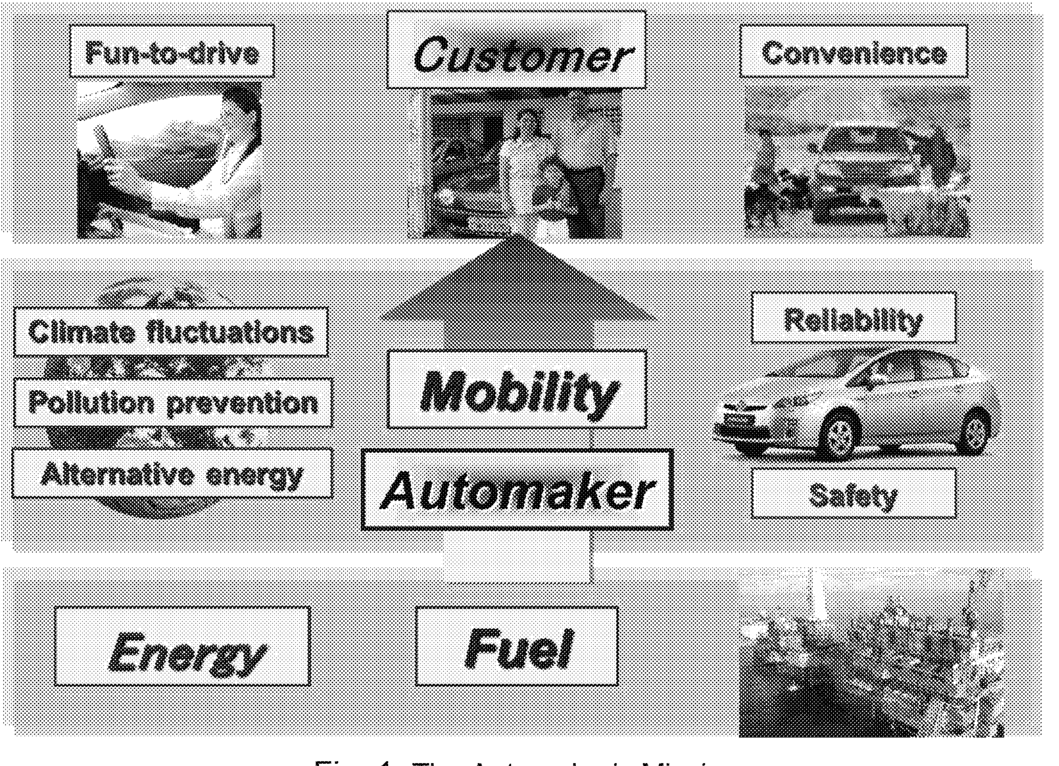

Fig. 1 The Automaker's Mission

2. History of Powertrain Development at Toyota

Toyota Motor Corporation began engine development in 1935 aiming to catch up with engines from Europe and the U.S. Since then, efforts have concentrated on the development of more efficient and cleaner engines through the growing adoption of electronic controls and four-valve technology.

In addition to engines for mass-production vehicles, Toyota has also developed a number of high performance G-series engines for sporty vehicles to deliver fun-to-drive performance. Furthermore, Toyota also achieved the world's highest maximum thermal efficiency at the time with the launch of the engine for the Prius hybrid electric vehicle (HEV) (Fig. 2).

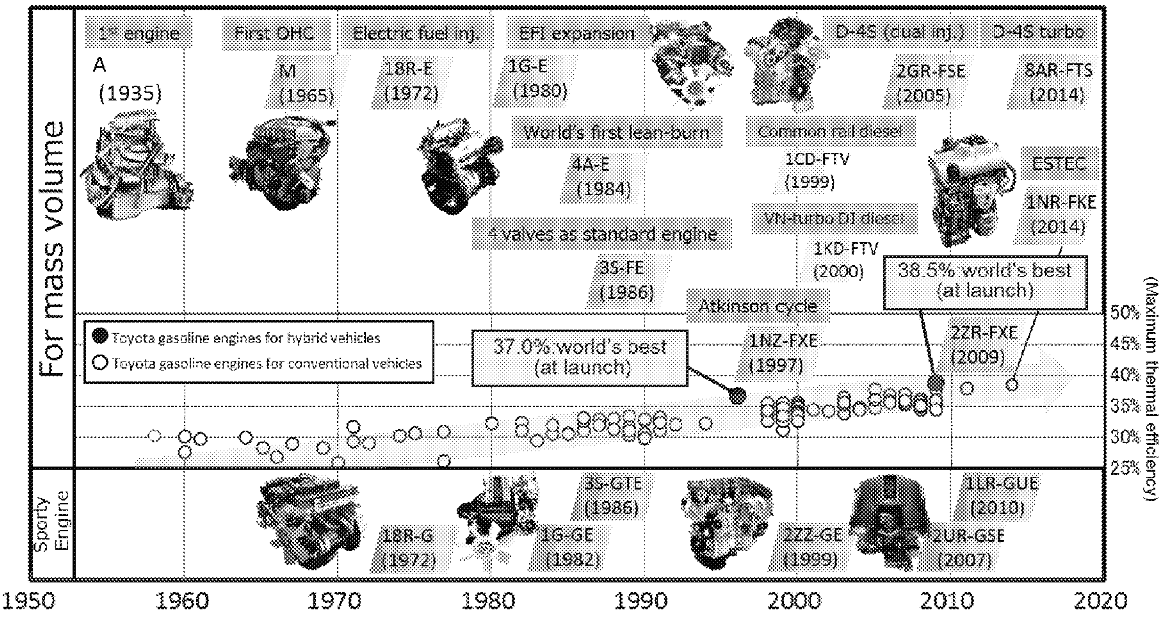

Fig. 2 History of Internal Combustion Engines at Toyota

Figure 3 shows the history of transmission development at Toyota. Starting from its first generation 3-speed manual transmission, the number of shift speeds has been increased for higher efficiency and automation has been promoted for more convenience. The trend for larger numbers of shift speeds has led to the emergence of continuously variable transmissions (CVTs) for further advances in efficiency and smoother driveability. Based on this concept, Toyota developed and adopted an electrical CVT for the Prius HEV .

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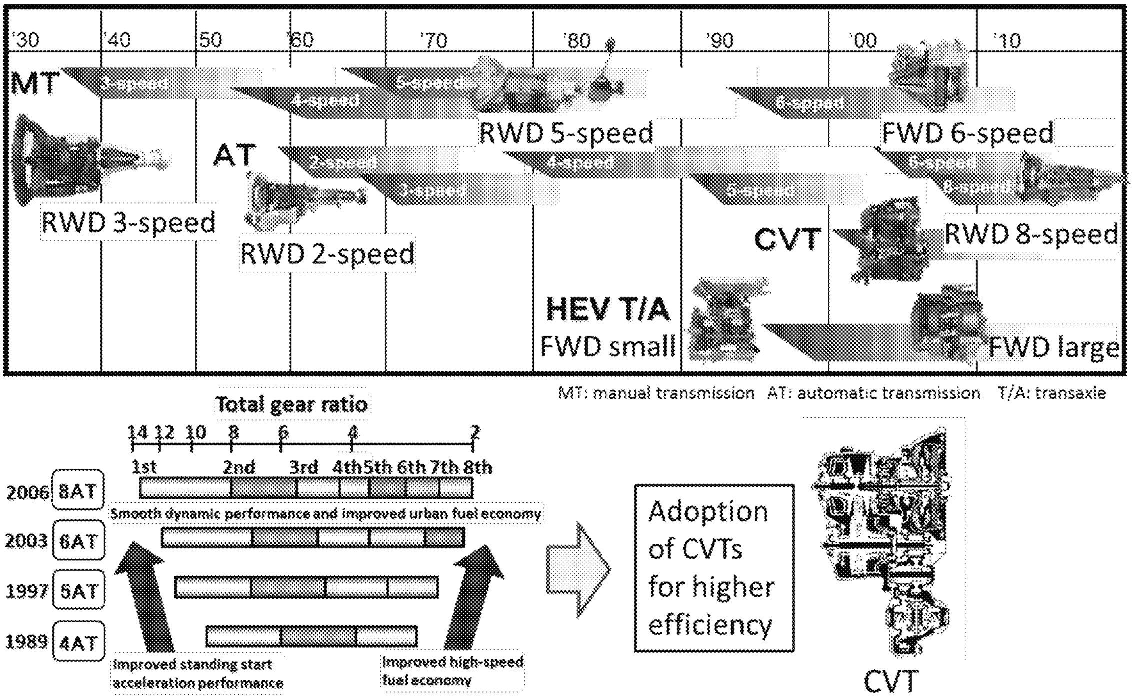

Fig. 3 History of Transmission Development at Toyota

Aiming to further improve fuel economy and reduce emissions, Toyota launched the world's first mass-produced HEV in 1997. Since then, Toyota has developed HEVs for every vehicle segment and total global sales exceeded 7.0 million in September 2014 (Fig. 4).

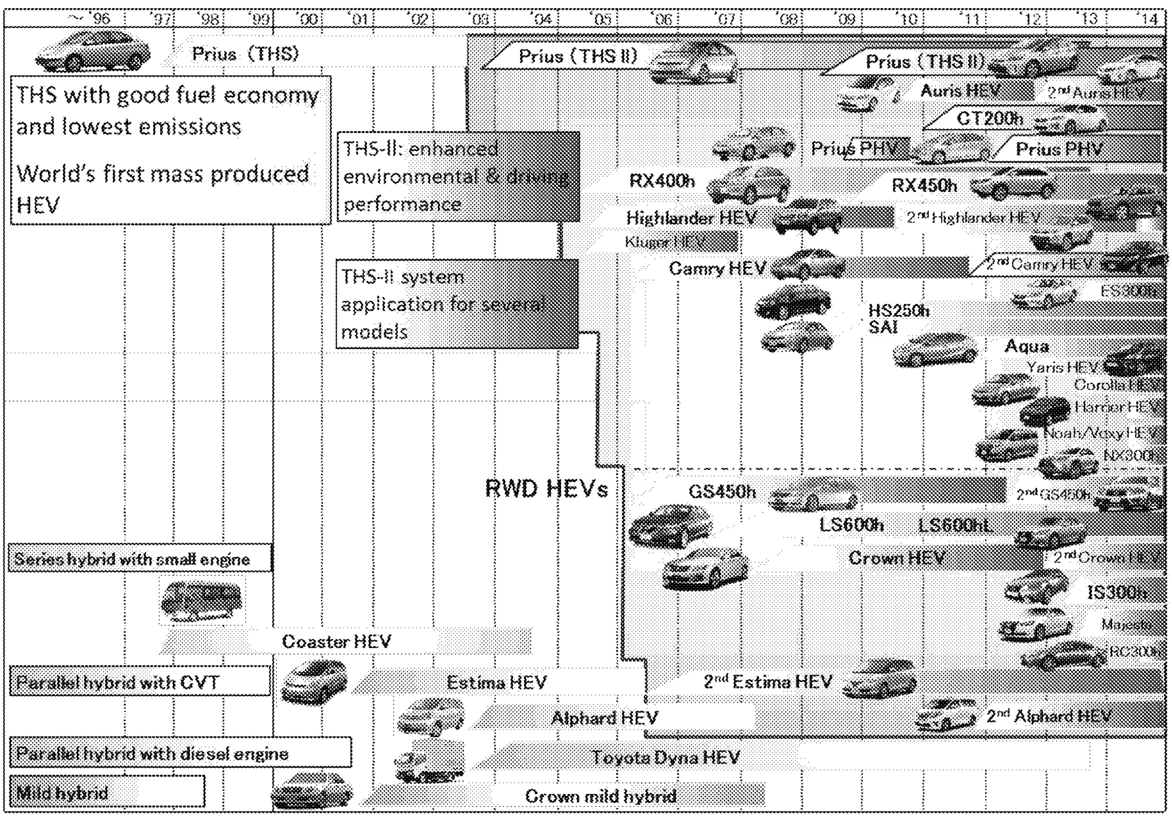

Fig. 4 HEV Development and Expansion

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A HEV powertrain consists of components such as a motor, inverter, and battery, in addition to controls. By developing all these elements in-house, Toyota has been able to minimize the combined losses of the HEV electrical powertrain and conventional engine, thereby helping to improve the energy efficiency of the entire HEV system.

A possible future evolution of the powertrain is the fuel cell vehicle (FCV), which uses hydrogen as a next-generation energy carrier. Toyota launched the Mirai FCV on the Japanese market in 2014.

Toyota develops and manufactures the core components of its FCV, i.e., the FC stack and hydrogen tanks, in-house to ensure both the environmental and conventional performance aspects of the Mirai (Fig. 5).

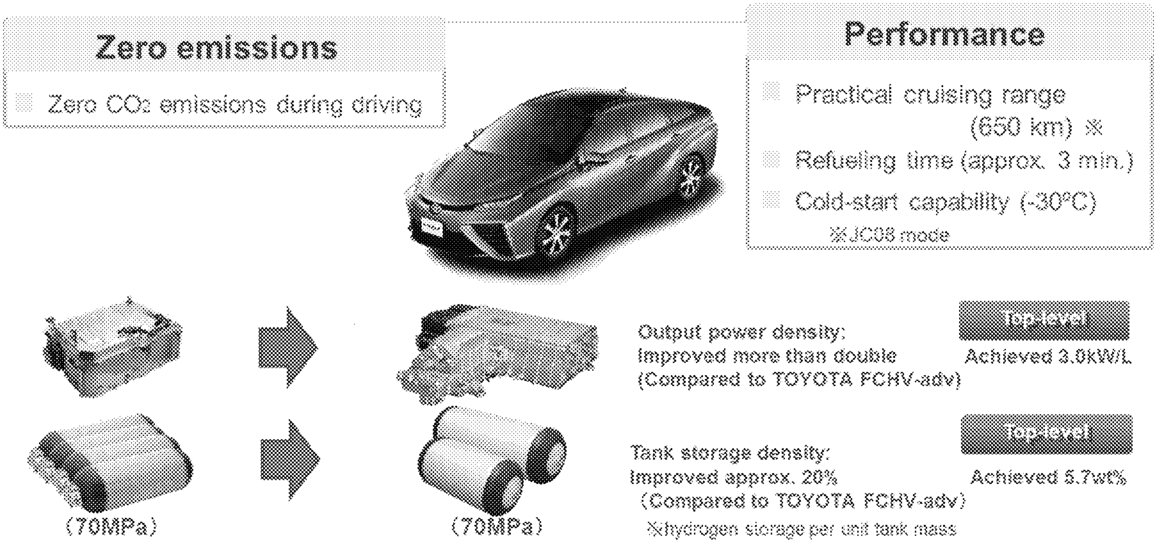

Fig. 5 Core FCV Technology

Figure 6 illustrates the advantages of in-house development of core components. Each component has visible design specifications and hidden background information that can only be gained through the development process. This background information obtained through in-house development is used to further enhance the development process, and to maximize synergistic effects through combinations with other information. To achieve these effects, engineers are required to have knowledge about different fields, which also helps to develop better human resources.

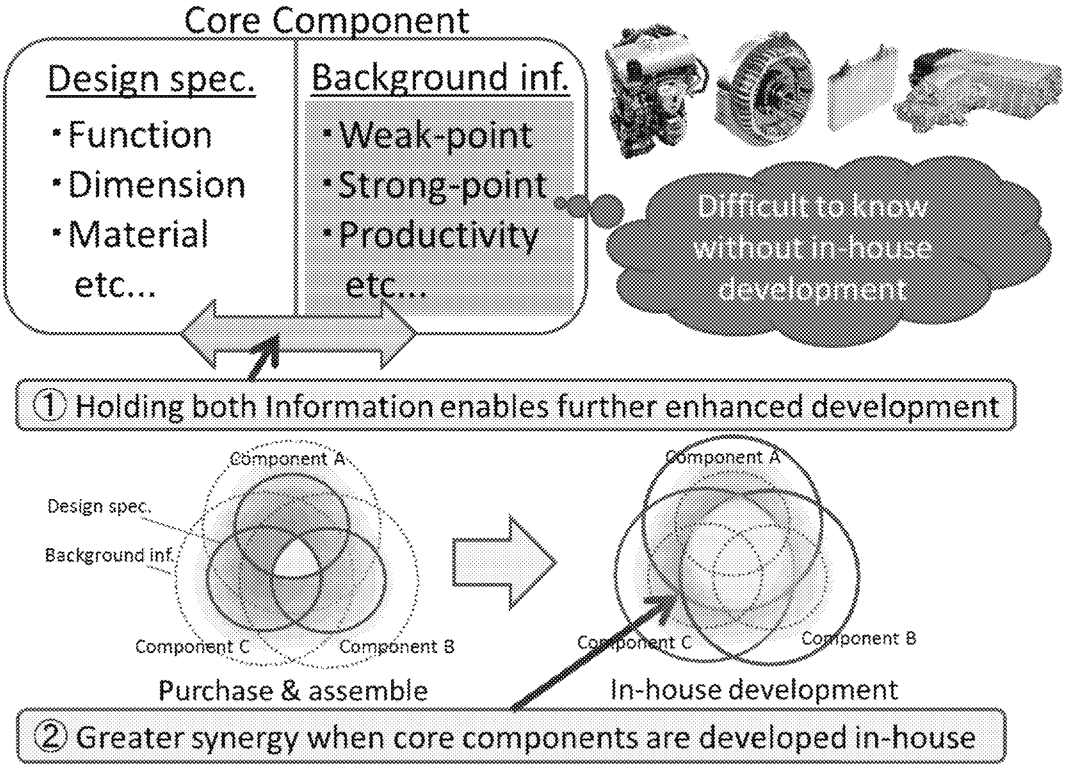

Fig. 6 Benefits of In-House Development

3. Future Direction of Powertrain Development at Toyota

As described above, a fundamental way of improving the energy efficiency of a powertrain is to develop more efficient components, such as engines, transmissions, motors, and inverters, and to minimize losses by compensating for individual weak points through the optimum combinations of components (Fig. 7).

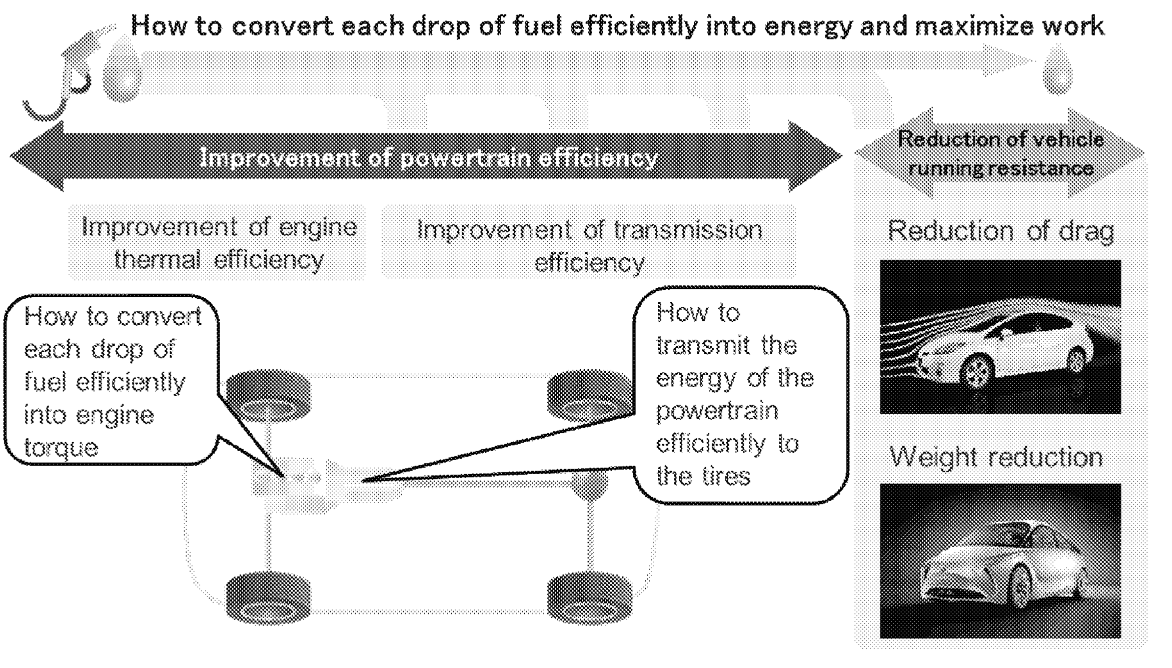

Fig. 7 Basic Ways to Improve Powertrain Efficiency

The same approach is important for improving the thermal efficiency of the internal combustion engine (ICE) in the case of both HEVs and conventional vehicles.

As the result of wide-reaching research efforts, Toyota's next-generation gasoline engines that are under development achieve higher thermal efficiency than Toyota's current engines for HEVs over a wider operating range (Fig. 8). Accordingly, the transmissions to be matched with these engines must ensure the capability of utilizing the highly efficient operation region of the engines.

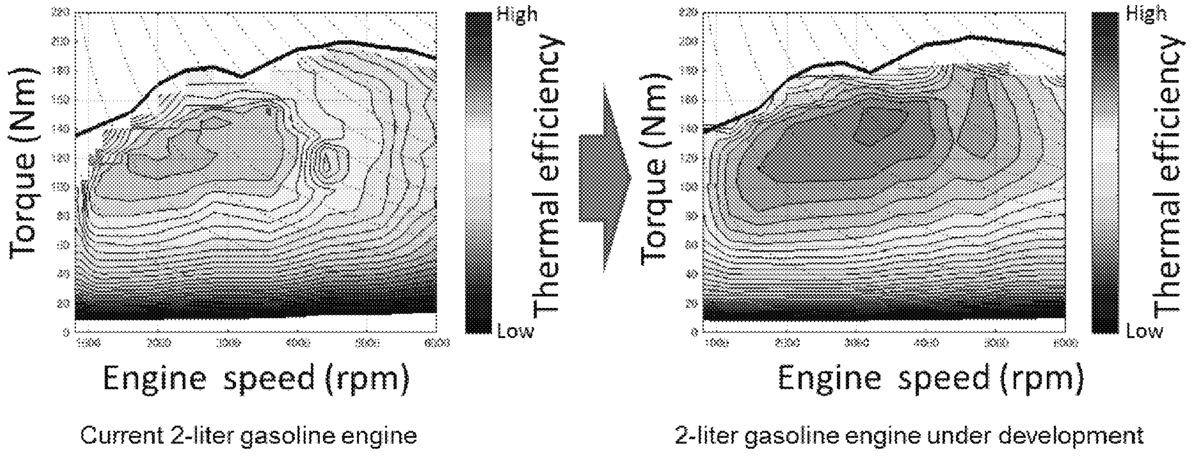

Fig. 8 Thermal Efficiency Improvement

The following section examines the effects of combining different engines and transmissions. Figure 9 compares the engine operating points for each transmission type (number of shift speeds) in small and medium class vehicles installed with a naturally aspirated (NA) gasoline engine.

This figure indicates that combining a NA gasoline engine with a CVT or a HEV CVT like the Toyota Hybrid System (THS) are effective ways of ensuring the engine operates in regions of good fuel economy. These combinations achieve the smallest amount of energy loss.

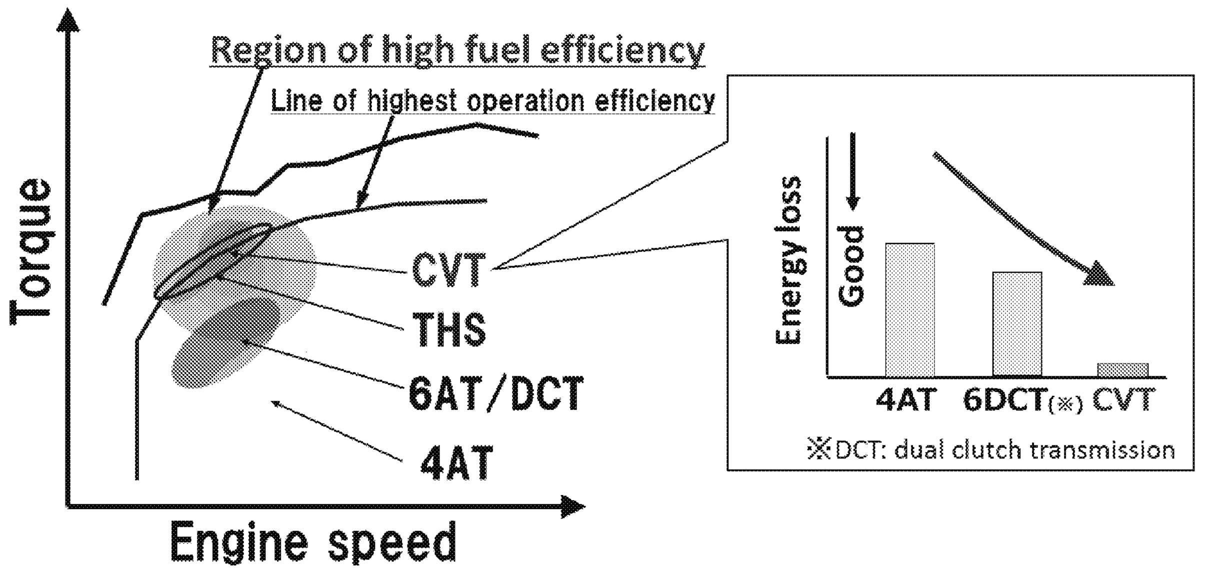

Fig. 9 Engine and Transmission Combinations (Small to Medium Class Vehicles)

Figure 10 compares the results of fuel consumption calculations in the NEDC using medium class vehicles combining a 2.0-liter NA gasoline engine with either a 6-speed automatic transmission (6AT) or a CVT, and a 1.5-liter downsized turbocharged engine with an 8-speed automatic transmission (8AT) for the same vehicle conditions (road load, inertia weight).

Combining the 2.0-liter NA gasoline engine with Toyota's newly developed CVT achieves better fuel economy than the downsized turbocharged engine. This is due to the improved CVT efficiency itself and because an NA engine is capable of achieving a higher compression ratio than a turbocharged engine, which enables high maximum thermal efficiency. The new CVT is then able to make effective use of this region of high efficiency.

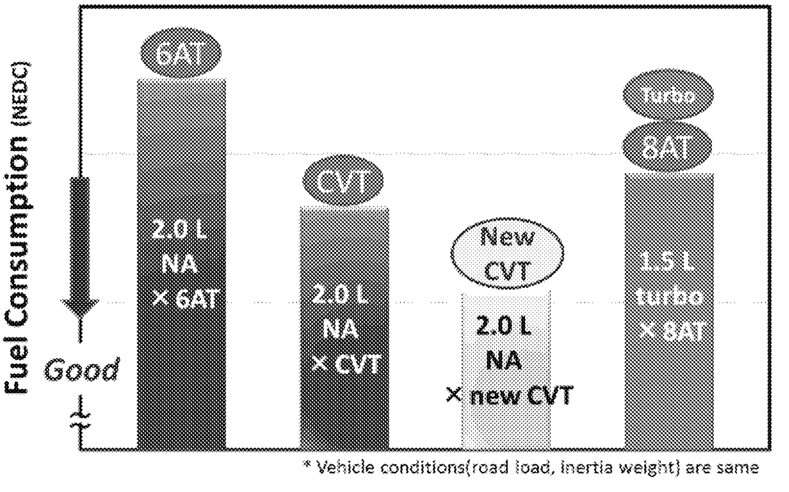

Fig. 10 Comparison of Fuel Consumption in Medium Class Vehicle(NEDC)

In addition, using the refined controls described in Fig. 11, the new CVT also eliminates the so-called rubber-band feeling (i.e. the sensation of sluggish reaction) of previous CVTs to create a feeling of smooth acceleration. In addition, the shifting time in manual mode has been greatly reduced to improve the feeling of direct control. This CVT has already been well-received in the Corolla launched in North America.

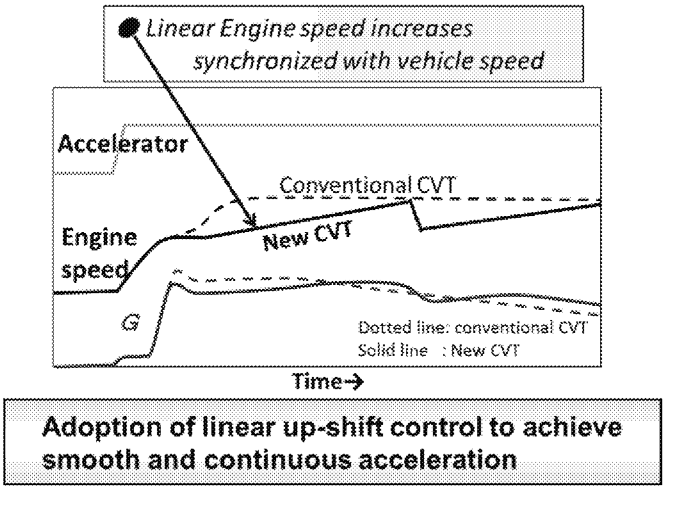

Fig.11 Improving Fun-to-Drive Performance of CVT

At the same time, powertrain development must also consider the market environment and how vehicles are used by the customer. Different countries and regions around the world have individual energy situations, road environments, and customer expectations. Rolling out a single powertrain in every region at the same time is unlikely to provide an effective solution for energy and environmental issues.

For example, differences in the road environment, such as the state of highways and congestion, yearly distances driven, fuel quality and price, and the availability of alternative fuels, are important consideration points of the optimum powertrain that we wish to deliver for each region and stage of development (Fig. 12).

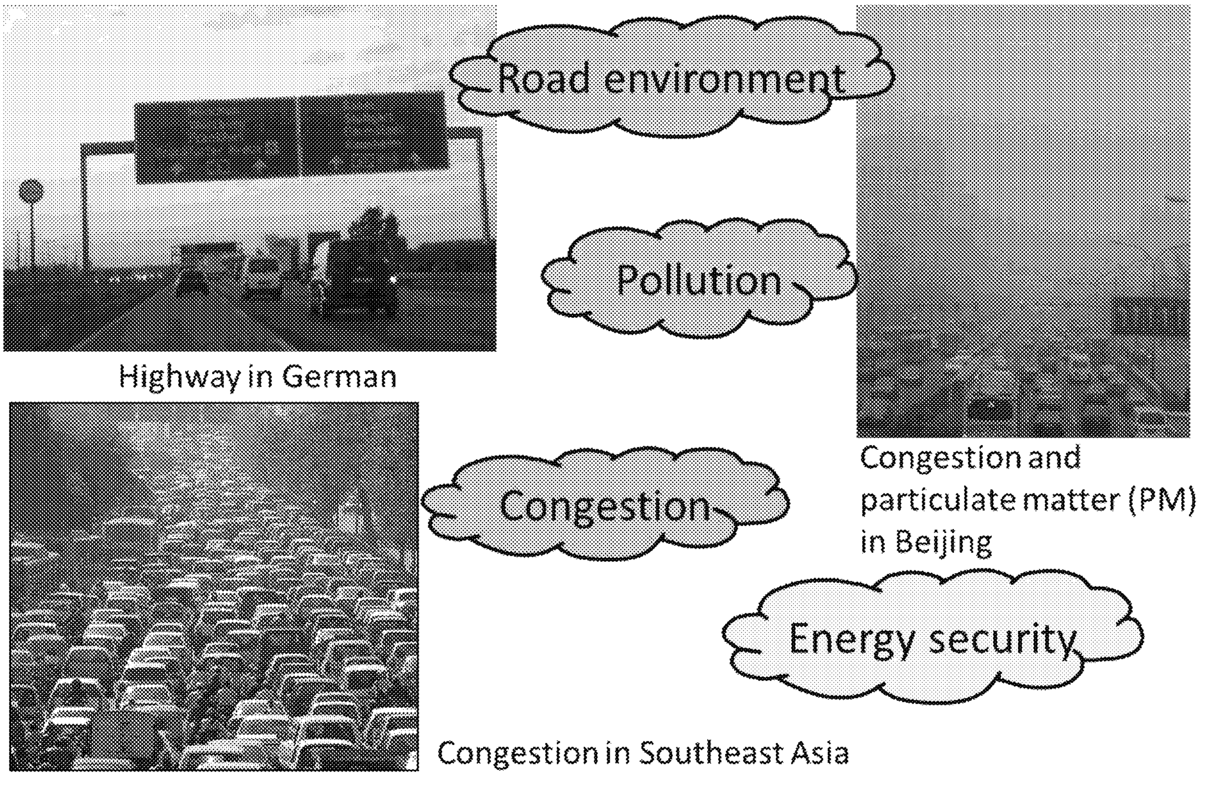

Fig.12 Range of Global Market Conditions

Figure 13 shows the relationship between engine power usage and thermal efficiency in typical driving patterns at high speeds and in congestion. For example, turbocharged gasoline engines and diesel engines that are more efficient at medium and high power ranges are effective at conditions shown in the upper graph, in which these ranges are used more frequently. These powertrains can also satisfy customers' expectations for dynamic performance. In contrast, the combination of an NA engine and a start and stop system, as well as the adoption of an HEV or electric vehicle (EV) capable of energy regeneration and motor drive are effective at conditions shown in the lower graph, in which stopping and low-power driving occur more frequently.

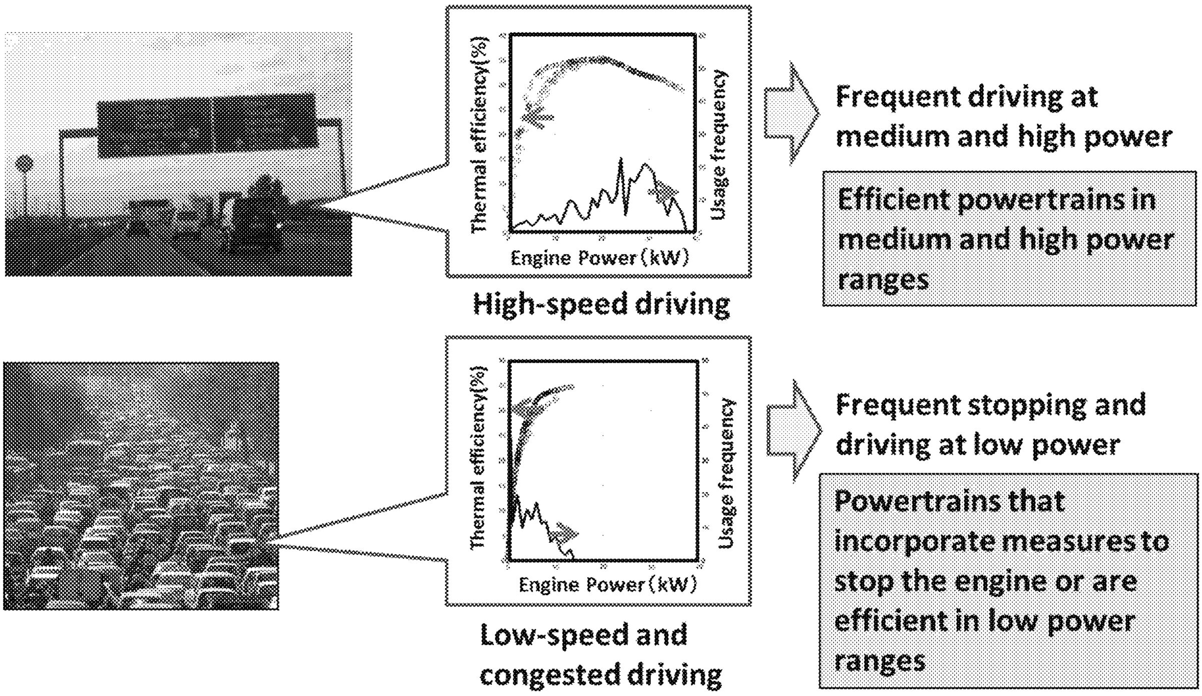

Fig. 13 Engine Power and Thermal Efficiency based on Customer Driving Patterns

As described above, Toyota develops the key components considering the vehicle class, regional characteristics, and customer usage, and then combines these components together to deliver the optimum powertrains (Fig. 14).

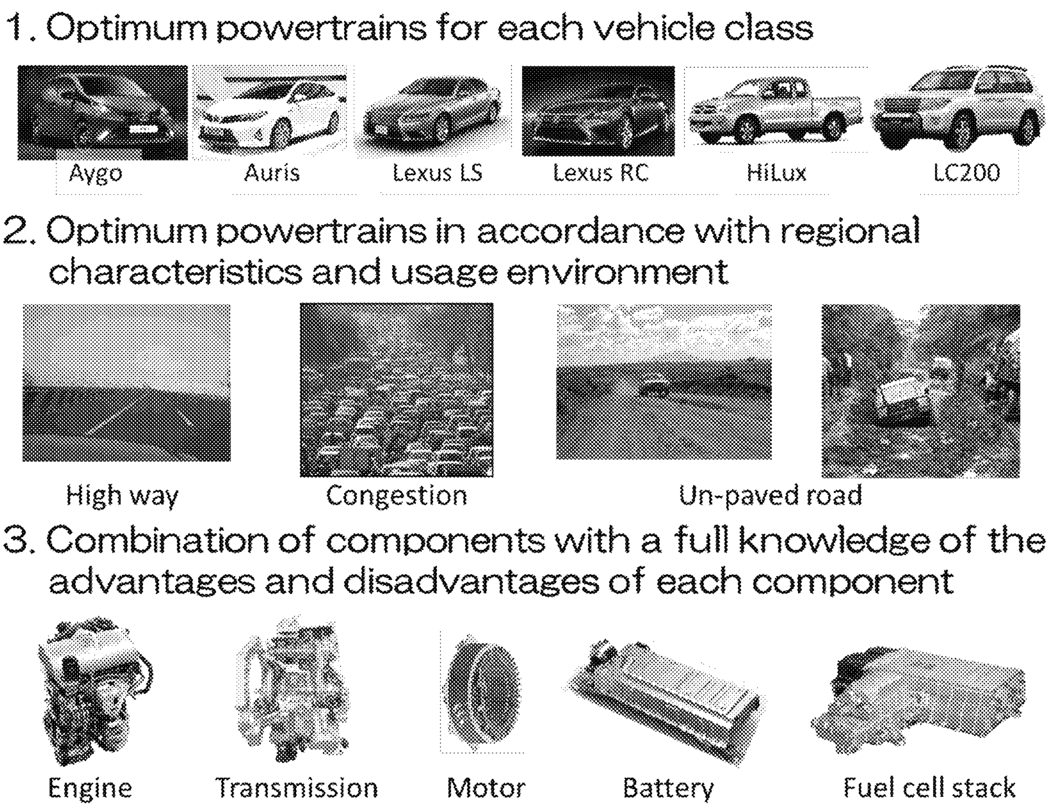

Fig. 14 Powertrain Optimization

To achieve this goal, Toyota is working to further enhance its range of powertrains including turbocharged gasoline engines, diesels, HEVs, PHVs, and FCVs. It intends to completely renew its whole powertrain lineup by 2020 to achieve the next level of higher efficiency (Fig. 15).

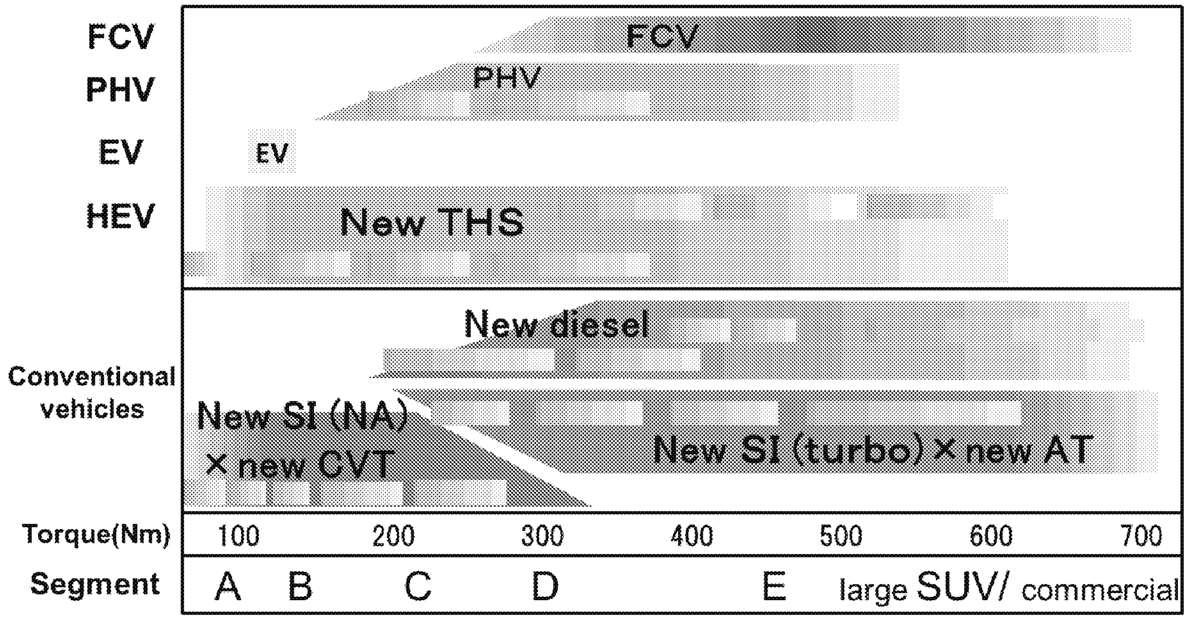

Fig. 15 Toyota's Future Powertrain Line-Up

4. Technological Progress and Future Prospects for Next-Generation Vehicles

Figure 16 overlays the fuel economy potential of conventional powertrains, HEVs, and PHVs onto the likely trends of future fuel economy regulations, using C-segment vehicles as an example. This figure indicates that, in the near future, conventional powertrains alone will not be sufficient to comply with fuel economy regulations. As a result, each automaker will have to increase the proportion of next-generation vehicles such as HEVs, PHVs, and EVs in its lineup.

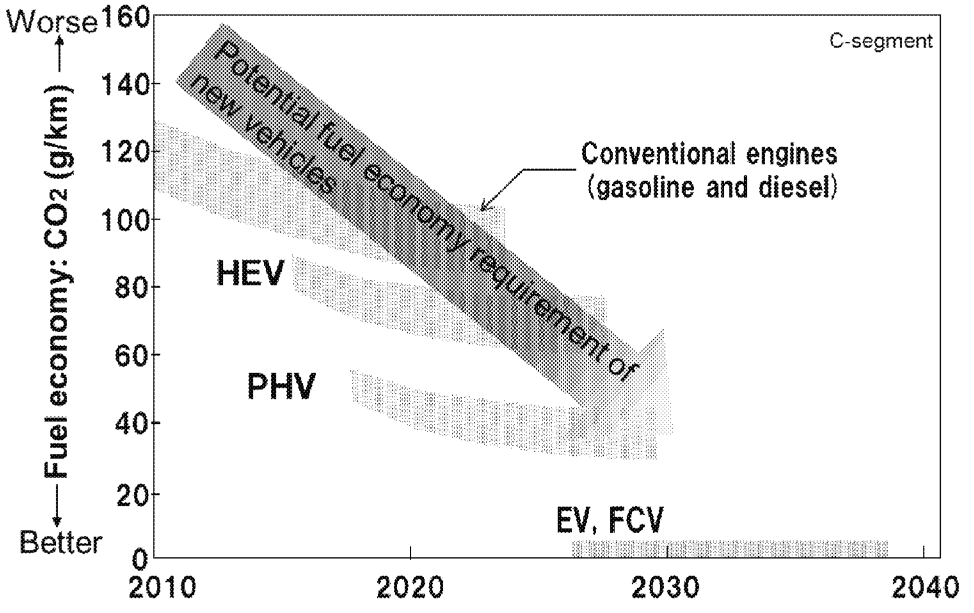

Fig. 16 Image of Fuel Economy Regulations and Potential of Each Powertrain

As part of its approach for achieving zero tailpipe emissions, Toyota launched the eQ, an EV equipped with lithium-ion (Li-ion) batteries, in Japan and the U.S. in 2012. However, solutions have yet to be found for the fundamental issues of EVs, such as driving range and cost (Fig. 17).

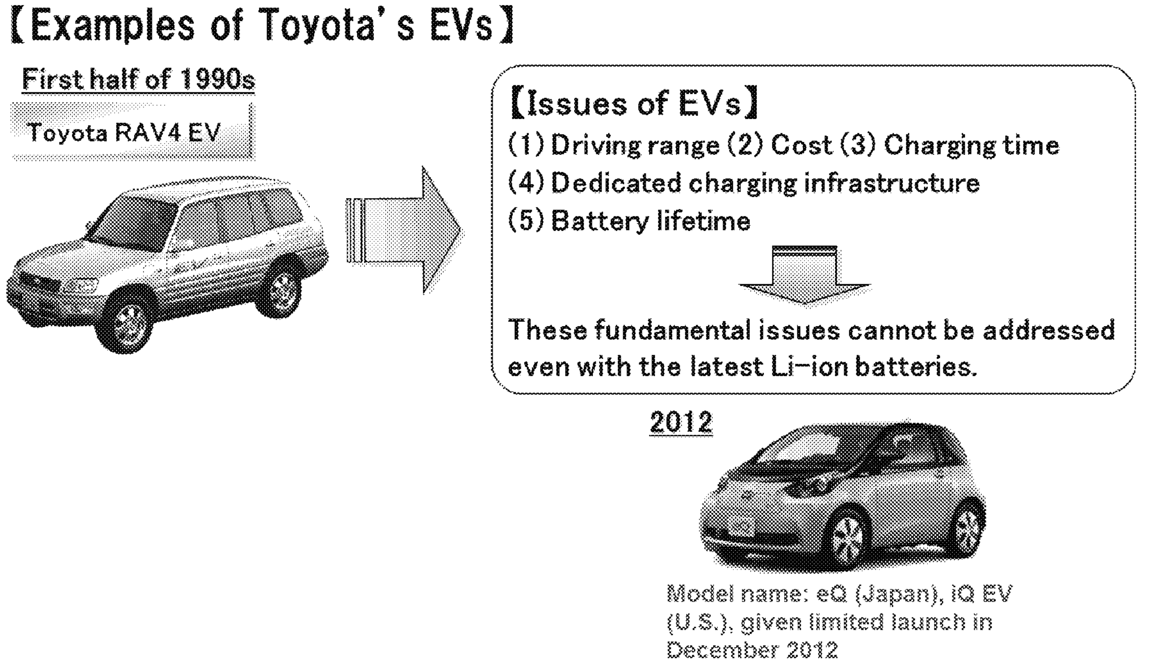

Fig. 17 Toyota's EVs in 2012

Toyota regards FCVs as a promising means of resolving the fundamental driving range and charging time issues of EVs, while maintaining the high environmental performance of zero tailpipe emissions. Toyota began developing FCVs in 1992 and launched the world's first mass-production FCV, the Mirai, in Japan in December 2014 (with launches planned for Europe and the U.S. in the autumn of 2015).

As shown in Fig. 18, since hydrogen has a higher energy density than batteries, FCV system costs do not increase as much as that of an EV even if the tank volume is increased to extend driving range.

For this reason, FCVs have the advantage over EVs in medium and long travel distances.

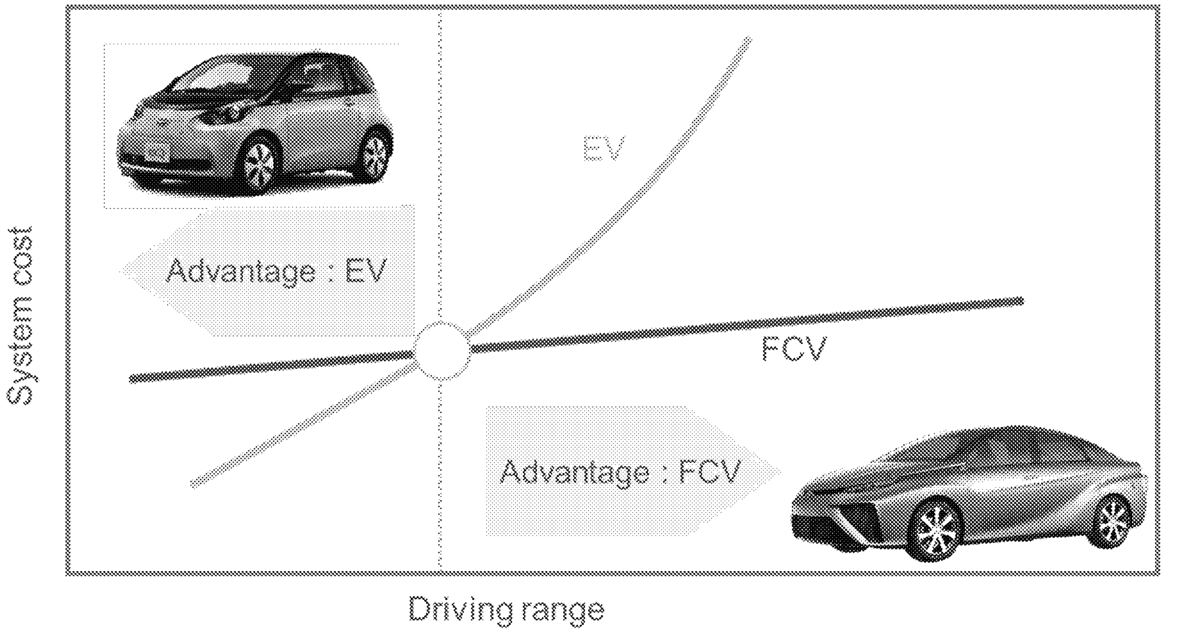

Fig. 18 Comparison of System Cost between EV and FCV Based on Driving Range

Figure 19 shows Toyota's vision of the separate mobility zones that may emerge in the future based on the characteristics of the various powertrains described above.

Excluding special circumstances in some countries, the issues with driving range and charging time mean that EVs are more suitable for short distances.

In contrast, HEVs and PHVs, which incorporate the performance and convenience of conventional powertrains, are more suitable for the range of uses required of first cars. These vehicles are appropriate for all regions since the ICE in these vehicles can be used with various alternative fuels as well as gasoline or diesel.

Finally, FCVs have a longer driving range and shorter refueling time than EVs and are therefore suitable for a wider range of applications. However, the popularization of FCVs will be required the simultaneous progress of FCVs and hydrogen infrastructure establishment.

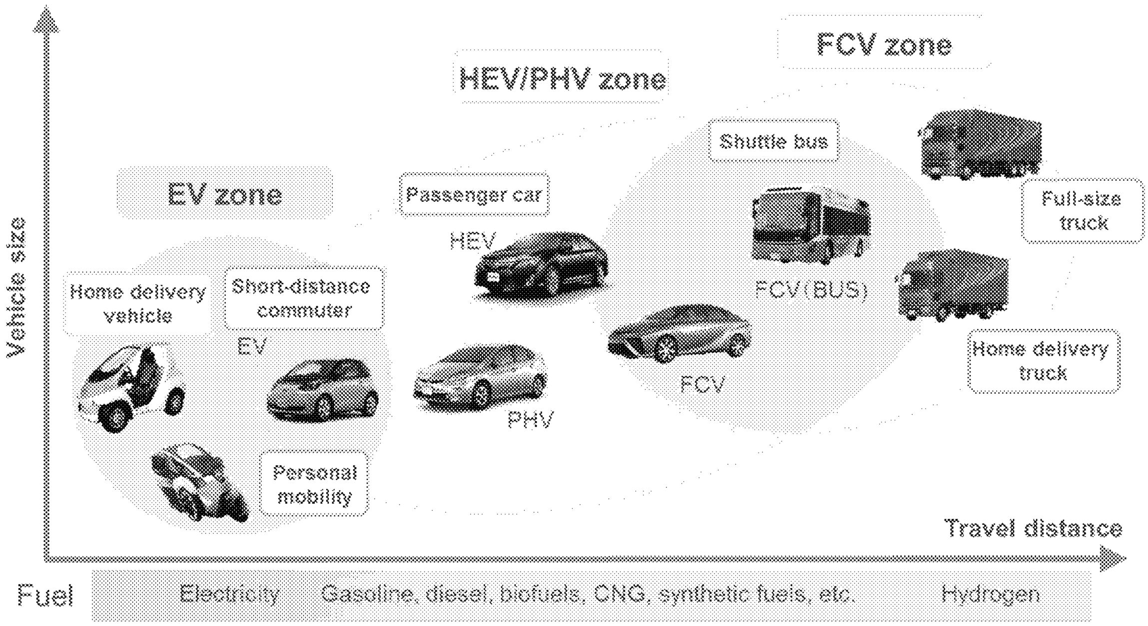

Fig. 19 Toyota's Vision of Mobility Zones

Finally, Fig. 20 shows Toyota's concept of a sustainable energy society. Electricity will remain an important energy medium into the future. However, this concept envisions the development of a hybrid power grid (called a "HyGrid") that combines electricity with hydrogen as a means of energy storage. Surplus fossil fuel energy and electricity generated at various locations and times can be converted into hydrogen and then re-converted into electricity with minimal losses wherever required. This form of energy usage with little waste is regarded as a future vision for mobility that integrates smoothly with the next-generation energy society.

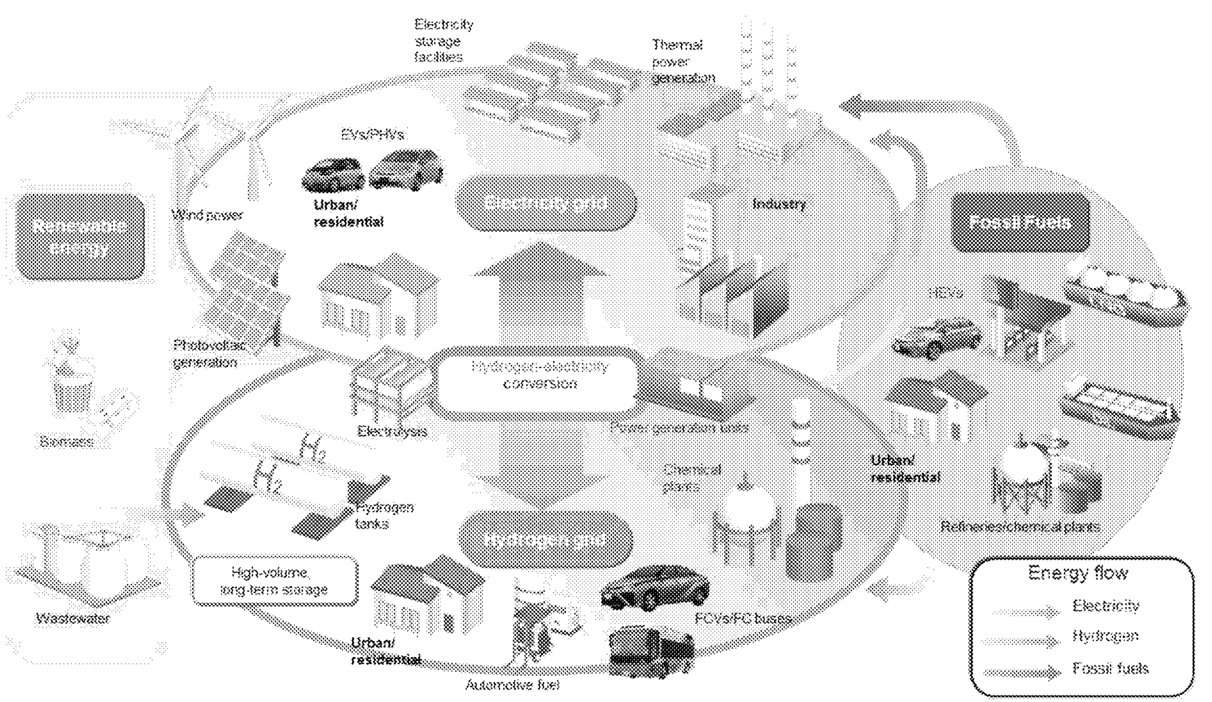

Fig. 20 "HyGrid" Concept for Hybrid Electricity and Hydrogen Grid

5. Summary

In-house development of core technologies is the key element of Toyota Motor Corporation's philosophy to deliver optimum powertrains to customers in every region around the world. In the future, Toyota intends to continue the following activities as part of its customer-centered vehicle development:

(1) Minimize tank-to-wheel energy consumption and the burden on environment. Develop all core technologies of the powertrain in-house, from conventional models to those adapting to diverse energy sources.

(2) Deliver optimum powertrains for each region around the world in accordance with the energy situation and vehicle usage environment in that region.

(3) Propose concepts for the next-generation energy society that integrate communities with mobility, and take leadership in activities to achieve these concepts.

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